Assessment of Damage to Framed RCC Structures in Gujarat Earthquake and Retrofiting with Fiber Wrapping Technique

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Observations on Structures Damaged by Earthquake in Gujarat

After the earthquake a number of structures in Ahmedabad, Rajkot, Surendranagar were inspected to see the effect of earthquake. It revealed that buildings done with good structural system (though not necessarily designed to resist earthquake) have not been damaged. Good structural system includes:-

1. Provision of adequate number of columns arranged in a way to give clear earthquake resistant frames in all directions,
2. Provision of tie beams.
3. Resting of foundation on firm strata.
4. Good quality of construction
5. Use of stiff shear wall elements like staircase shaft by tying all the floor beams rigidly to it.
6. No excessive cantilever elements etc.

Structures in the areas close to earthquake epicenter such as Bhuj, Bacchav, Anjar - Load bearing structure in loose mortars damaged. Many of the RCC structures also collapsed. Surprisingly even in these areas RCC elevated water tanks exhibited remarkable resistance to earthquake forces. The prime reason for this is better quality compared to residential structures and a well defined, organized structural system.

Among collapsed buildings with G+4 or Parking + 5 structures most cases damage was to the parking side or consequently to the entire building. In many buildings of this type other buildings where collapse has not taken place, there are various types of damages of lesser severity.

TYPES OF DAMAGES

1. Collapse:

The entire structure has collapsed. The initial failure may have been localized but consequently led to overstressing of other elements and led to total collapse.

2. Sinking of lower stories:

In these cases the parking side columns gave away first. This was followed by collapse of this part of the building. In the process in many cases the story just above parking also crushed to debris.
Sketches 1 and 2 illustrate how the collapse has taken place. Photographs 1 and 2 also show the collapsed buildings. Surprisingly the upper stories appear to be in good condition.

3. Crushing of columns locally without total collapse

This is a localized damage. They were observed mainly on columns and that too in the location just below parking columns where the moment is maximum. Sketch 3 shows the typical location of damage. In some columns where there was lack of confinement due to absence of links localized damage is seen. See Photograph 3.

4. Cracking in columns (at beam column junction, at column lift junctions as well as cross type cracking)

5. Shear cracks in beams.

6. Cracks in cantilever brackets supporting floating columns. These cracks were just

adjacent to column face supporting the bracket.

7. Horizontal cracks in columns, which support brackets. These cracks appeared just below the lower end of the bracket due to shear in column.

8. Sagging of large span beams

9. Cracking at the top of staircase flight (at the flight and landing junction)

Except total collapses as in type land 2 above, other types of distresses can be addressed to by using retrofitting technique such as fiberwrapping.

METHODOLOGIES OF REPAIRS & RETROFITTING

1. Epoxy Injection Grouting into cracks
2. Repairing crushed damaged portions with Polymer/ epoxy mortars
3. Confining the damaged portions for improving their strength with reinforcing steel & concrete encasing, ferrocement encasing, fiber wrap encasing
4. Improving ductility of beam col. Joints

FIBERWRAP METHODOLOGY

This is a relatively new technique. Surface preparation is very critical for this application. The steps for retrofitting are as follows

1. Remove plaster, loose concrete etc and clean the surface thoroughly. The surface should be very even, with convexity removed by grinding Round the comers to a radius of 25 to 30 mm avoid stress concentration
2. Apply epoxy primer. Surface concavity is to be filled by epoxy or other suitable putty.
3. Apply saturant epoxy on the surface.
4. Stretch unidirectional E- glass fiber cloth or bi directional E-glass + Aramide fibers over the surface.
5. Saturant should ooze out of fabric or else apply a second coat of saturant.
6. Repeat process depending upon the layers designed

ADVANTAGES OF FIBER REINFORCEMENT

The Fiberwrapping technique of retrofitting is relatively easy for application. It has a high strength to weight ratio. Fiber a~ ,~ell the resin in which it is saturated, are both resistant to corrosion under
the attack of chemicals. The fiberwrap skin is also resistant to environmental degradation. It also has tailorability to adapt to any shape of .the substrate concrete.

FIELD SCENARIO

Until recently application of composites in civil engineering was very limited. This was on account of high cost and lack of availability. Recent advances in manufacturing of composites have opened out potential to make large components with quality adequate for civil engineering applications. Reduced demand from defense (particularly Carbon fibers) made availability of fibers easy. Since the composites, when used in conjunction with conventional material like steel ands concrete, can be designed with conventional structural analysis methods, it has enabled to make them popular.

APPLICATIONS IN CIVIL ENGINEERING

1. FRC can be used in the form of plates to improve tension capacity of flexural members (as against steel plates).
2. Bars- as reinforcement replacing steel.
3. Cables- as .tendons and members in suspension structures.
4. Wrap- around concrete members to confine concrete and improve

strength and ductility. This last application is very useful in retrofitting of earthquake damaged structures.

CONFINING ACTION

Tensile strength of concrete is negligible in comparison to its compressive strength. Even compression members often fail due to tensile stress that develops in perpendicular direction. Confinement
increases strength and other properties. The confining action of the wrap is created through passive restraint of transverse dilation of concrete under uni-axial compression. The confinement in the
form of externally applied fiber reinforced composite jacket places the concrete under state of hydrostatic or tri-axial compression.

TYPES OF FIBERS

Table 1 gives the mechanical properties of commonly used fibers for FRP wrapping. The selection of fibers for a particular application depends upon the requirement of the section. Usually for high strength application where deformations are critical it is desirable to use high strength and high modulus carbon fibers. For applications where ductility improvement is to be given by fibers (strength is adequately provided by steel and concrete) then e-glass fibers would suffice.

SOME TEST RESULTS USING FRP WRAPPING AT LABORATORY LEVEL

Table 2 gives the results of confinement on cylinder specimen with e-glass fiber wrapping using GOLDBOND system. These were conducted in connection with wrapping work done at corporate office of KRIBHCO at Ahmedabad during retrofitting after earthquake.

Table 3 highlights the improvement in strength of columns, which are repaired by wrapping after failure. It also shows the capacity improvement of columns where wrapping was done prior to initial loading.

Table 4 shows results of improvement of flexural capacity of beams where pultruded sheets were glued to the beam bottom.

All these tests Indicate the effect of fiber wrapping.

DESIGN PRINCIPLES

Strengthening for Axial load

For appreciating the behavior of FRP confined Concrete under axial load a study of circular section is illustrative.

1. Strain in jacket is equal to transverse strain in concrete.
2. Transverse expansion of concrete is in turn dependent on longitudinal strain of concrete.
3. Thus as axial strain increases, transverse strain increases and confining pressure increases.
4. Analogy of thin walled cylinder gives confining pressure given by jacket.
5. Confining pressure increases compressive strength of concrete as compared to unconfined concrete.
6. FRP jacket improves shear strength of concrete. This is a function of fiber ultimate strength,number of layers and thickness.
7. If existing column is damaged and subsequently repaired then reduction of original concrete strength should be considered while designing the wrapping.
8. Active signs of corrosion as well as potential sites should be treated before wrapping. These would not be seen after wrapping. Corrosion inhibitor treatment is recommended.
9. Any other form of nonstructural cracking should be addressed. (Alkali Aggregate etc)

Strengthening for Flexure

1. Find initial strains in concrete before wrapping. (usually under only dead load)
2. Find the enhanced moment resisting capacity required. Also find the difference between existing

theoretical capacity and enhanced capacity.
3. Assuming an approximate lever arm for fiber layer, find additional tensile force required to be developed.
4. From fiber properties decide the fiber strip area (then thickness and layers etc).
5. Then do ultimate load analysis based on strain compatibility.
6. For this, iterative procedure is required by starting with a value of neutral axis depth.
7. Find mode of failure -concrete crushing or FRP rupture
8. Find strains and stress in concrete, steel and fiber. Check resultant stress equilibrium
9. Revise assumptions of depth of neutral axis, and continue iteration.
10. Finally once correct NA depth is found, find moment resistance capacity.
11. Fiber stress strain curve is assumed to be linear. For other materials use existing recommendations of codes.

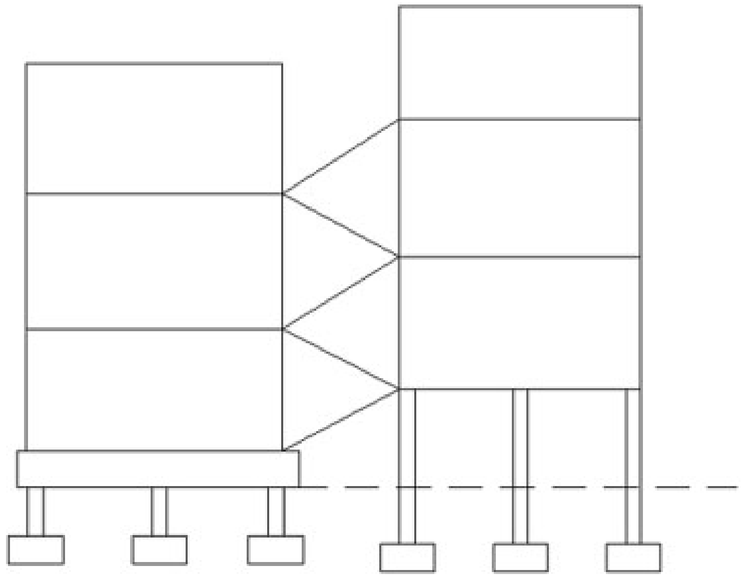
Strengthening for Shear

1. Methodology is similar to finding contribution by transverse steel reinforcement.
2. Reduction factor are applied to theoretical capacity because of possible failure modes of FRP strip such as bond failure, loss of aggregate interlock in concrete etc.
3. Depending upon the way the wrap in shear is possible, a reduction factor for effectiveness of wrap is required to be applied.

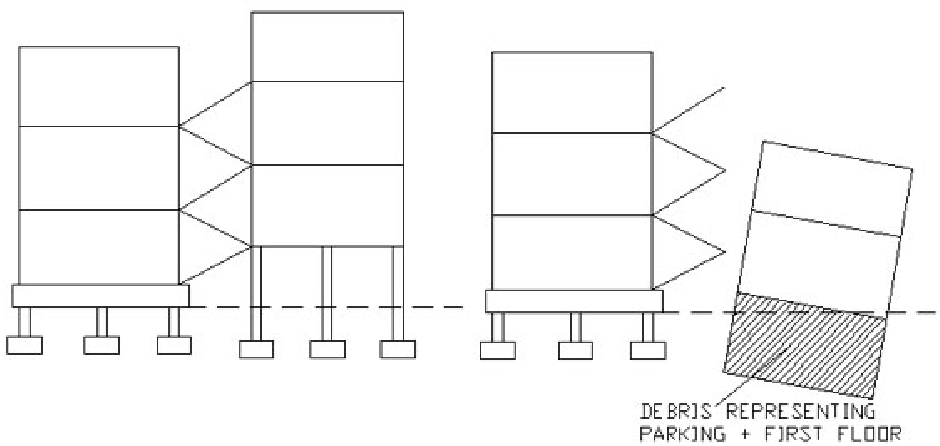
METHODOLOGY OF WRAPPING

1. Surface grinding to get an even surface. All projections are to be grounded off.
2. Grind sharp comers to 25 mm radius. This is to avoid stress concentration.
3. Apply putty on concave areas. The concavity can lead to air trapping inside and lack of full contact.
4. Apply primer to the prepared concrete surface.
5. Apply first coat of saturant by roller or brush.
6. Take precut FRP sheet, orient properly as per design consideration.
7. Place on saturant and press by rollers to squeeze out the saturant through the fabric. Air bubbles are also removed due to this operation.
8. Apply second ~oat of saturant to saturate the fabric fully.
9. For subsequent wrap layers follow the same set of steps except the surface preparation, primer and putty.
10. If any disbonded fabric or air entrapment is found then cut open and apply new patch of fabric after putty filling.

Photographs 4 to 8 show various steps in the process of fiberwrapping. Out of these Photos 4 to 7 are from a fertilizer plant in Gujrat and Photo no.8 is a commercial building in Ahmedabad. The system used for Wrapping is GOLDBOND 1893 from Krishna Conchem Products Pvt. Ltd.



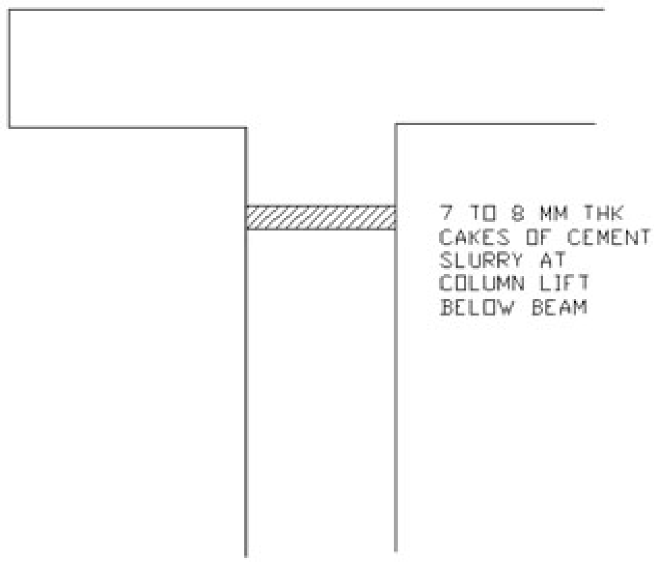
Sketch 1 : Typical Building with GF on one side and parking on other



Sketch 2 : The Collapse of parking floor along with one upper floor

Photo 1 : Collapse of Parking story-Snapped Column

Photo 2 : Collapsed Parking (Left), Parking + Upper (Right)



Sketch 3 : Typical Column Lift Top-Cement Slurry Cakes

Photo 3 : Absence Of Lateral Links In Columns and Failure

Table 1 : Type Of Fibers

	TYPES OF FIBERS		
FIBER TYPE	TENSILE STRENGTH N/mm2	MODULUS OF ELASTICITY kN/mm2	ELONGATION %
Carbon- High Strength	4300-4900	240-240	1.9- 2.1
Carbon- High Modulus	2740-5490	294-329	0.7-1.9
Carbon- Ultra High Modulus	2600-4020	540-640	0.4-0.8
Aramid- High Strength and High Modulus	3200-3600	124-130	2.4
E-Glass	2400-3500	70-85	3.5-4.7

Table : 2 Tests On Wrapped Cylindrical Samples

Test Results of FRP Wrapping :

At KBM Engineering Institute and Test Laboratory, Ahamadabad.

Test Cylinders : 150 mm dia x 300 mm height – water cured.

Date of Wrapping : 07-01-2002

SP No.	Date of Casting	Concrete Mix	Date of Test	Cylinder Status	Breaking Load MT	Strength Kg/cm2	Remark
1.	21-12-01	M-10	9-1-02	U.W.	45.75	259	Tests after 36 Hrs of wrapping for specimen 1 to 7
2.	21-12-01	M-10	9-1-02	Single wrap	87.00	492	
3	07-12-01	M-20	9-1-02	U.W.	59.00	333.70	
4.	07-12-01	M-20	9-1-02	Double wrap	148.0	837.10	
5.	07-12-01	M-20	11-1-02	Single Wrap	60.00	339.35	Loaded upto 60 MT wrapping cut down, the cylinder crumbled.
6.	10-12-01	M-20	11-1-02	Double wrap	80.00	452.50	Loaded upto 80 MT. The load released and wrapping cut down . Hair cracks observed. Again given load of 25 MT for crushing

Table 3: Tests On Columns Strengthening By Wrapping

	UNCONFINED, REPAIRED AND STRENGTHENED COLUMNS					
	SR	TYPE	FAILURE LOAD UNCONF KN	FAILURE LOAD CONF. KN	% INCREASE	STRAIN AT FAILURE
END WRAP	1	Repaired 2 layers	370	660	78	0.0066
	2	Repaired 4 layers	390	680	74	0.0083
	3	Strengthened 2 layers	365	745	104	0.012
	4	Strengthened 4 layers	395	780	97	0.013
FULL WRAP	5	Strengthened 2 layers	400	835	109	0.014
	6	Strengthened 4 layers	400	897	124	0.0176
	7	Strengthened 6 layers	400	937	134	0.0215

Column size = 150 x 150 x 1200 reinforced

wrap = oriented e-glass with polyester resin

Table 4 : Results Of Improvement In Flexural Capacity Of Beams With Pultruded FRP Sheets Glued To Bottom

	First Crack & Ultimate Moments of S/S beams strengthened with e- glass strips bonded to bottom		
Sr	Beam Type	First Crack Moment KN-m	Ultimate Moment KN-m
1	Unreinforced beams without any fiber reinforcement	0.196	0.578
2	Reinforced with 50 mm2 steel and without any fiber reinforcement	0.66	2.41
3	Reinforced with 100 mm2 steel and without any fiber reinforcement	2.6	2.91
4	Unreinforced beams with 25 mm wide fiber strip reinforcement	0.825	1.25
5	Unreinforced beams with 50 mm wide fiber strip reinforcement	0.925	2.115
6	Reinforced with 50 mm2 steel and with 25 mm fiber strip reinf	0.9	3.06

Photo 4: Putty filling and Surface preparation

Photo 5 : Applying Saturant and E-Glass Fiber Cloth

Photo 6 : Application of Slide Wrap on beam column junction

Photo 7 : Column junction wrapping in progress

Photo 8 : Wrapping of damaged columns in a commercial building